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FROST INJURY TO TOMATOES.[1]

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CONTENTS.

INTRODUCTION.

The importance of our tomato industry and the fact that a large part of the crop is shipped and handled during the winter and early spring months make the knowledge of the freezing temperatures of tomatoes of considerable economic importance to growers, shippers, and handlers of this crop.

Some idea of the scope of the tomato industry in the United States may be obtained from the following statistics compiled by the Bureau of Markets of the United States Department of Agriculture. Farmers' Bulletin 1233, "Tomatoes for Canning and Manufacturing," contains some additional data on the importance of the industry (*1*)[2]. During the year 1919 approximately 14,469 cars of tomatoes were shipped to all markets. In 1918 the number of cars was 15,458; in 1917 there were 13,910 cars; and in 1916 14,749, making a 4-year average of 14,646 cars. The States which ship field-grown tomatoes to the early market are Florida, Mississippi, Texas, and California, and they furnished 8,184 cars, or 56 per cent, of this yearly average. The total production and value of the crop of tomatoes for shipping from these four principal States in 1919 are shown in Table 1.

[1] This bulletin presents the results of a portion of the work carried on in the Bureau of Plant Industry under the project "Factors Affecting the Storage Life of Vegetables."

[2] The serial numbers (italic) in parentheses refer to "Literature cited," at the end of this bulletin.

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TABLE 1.—*Production and value of tomatoes shipped from the principal shipping States in 1919, according to statistics prepared by the Bureau of Markets.*

State.	Production.	
	Tons.	Value.
Florida	58,520	$9,714,320
Mississippi	18,400	1,692,800
Texas	17,700	1,628,400
California	17,380	729,960
Total	112,000	13,765,480

The heaviest of these car-lot shipments are made during the months of March, April, May, and June, although in Florida shipments in car lots begin in December. Smaller quantities of tomatoes are also shipped from Mexico, Cuba, and the Bahamas. These very early grown fruits supply the holiday markets in the large cities and represent a comparatively high money value. Michigan, Colorado, Iowa, New Jersey, and Virginia also produce large quantities of tomatoes, but their crops are grown chiefly for local consumption and canning. Their period of production extends from about June until the vines are killed by frost in the fall. (Table 2.)

TABLE 2.—*Statistics compiled by the Bureau of Crop Estimates and the National Canners' Association on tomatoes used in the United States for manufacturing and canning in 1918, 1919, and 1920.*

Items of comparison.	1918	1919	1920
Area grown ... acres	317,102	195,645	244,745
Yield ... tons	1,323,059	724,912	1,003,358
Cases (each containing 24 No. 3 cans)	15,882,372	10,809,660	11,368,000

Somewhat over half of our tomato crop, then, exclusive of canning tomatoes, is grown in the South and Southwest and shipped to the northern markets in the winter and spring months, when a good part of the product in transit and on the market is in constant danger of freezing. A considerable portion of the crop is usually cut short in the fall by early frosts while most of the vines are still producing vigorously.

Many data covering a period of three years have been accumulated in the Bureau of Plant Industry on the freezing points of a number of varieties of tomatoes, in both green and ripe stages; also data bearing on the freezing of tomatoes in the field. These results are incorporated in this bulletin.

VARIETIES STUDIED AND RESULTS.

Freezing points, or the temperatures at which tomatoes freeze, were determined on authentic varieties grown by the Department of

Agriculture at the Arlington Experimental Farm, near Washington, D. C. The varieties were Bonny Best, Olney Special, Earliana, John Baer, Landreth, Early Michigan, Marvel, Bloomsdale, Red Rock, Trucker's Favorite, New Glory, Stone, Greater Baltimore, Columbia, Delaware Beauty, Livingston's Globe, Livingston's Acme, Sunrise, and Sterling Castle. Since most of the tomatoes are shipped while still green but practically full grown, freezing points in many of the varieties were determined on full-grown green tomatoes as well as ripe ones. These determinations were made by subjecting them to an air temperature of about 15° F. As it had been found by previous tests that no differences in results were obtained by using portions of tomatoes instead of whole fruits and since the work could be carried on more rapidly by using only portions, this method was largely followed. A good representative sample of each fruit was obtained by cutting with a sharp cork borer parallel to a septum between the sections, thus removing a portion of both flesh and pulp. Temperature records were made by the thermoelectric method, using the thermocouples described by Taylor (*4*) with the White potentiometer. In Table 3 are shown the average freezing points of the varieties mentioned, which are arranged in the order of the earliness of the first picking of ripe fruit. Each freezing point given represents the average for a number of different pickings of each variety.

TABLE 3.—*Average freezing points of 19 commercially grown varieties of tomatoes.*

Variety.	Ripe.		Green.		Variety.	Ripe.		Green.	
	Freezing point.	Number of determinations.	Freezing point.	Number of determinations.		Freezing point.	Number of determinations.	Freezing point.	Number of determinations.
	° *F.*		° *F.*			° *F.*		° *F.*	
Bonny Best	30.60	27	30.57	6	Stone	30.31	21	30.15	5
Olney Special	30.59	5	......	......	Greater Baltimore	30.62	16	......	......
Earliana	30.52	17	30.24	10	Columbia	30.31	20	......	......
John Baer	30.57	21	30.53	7	Delaware Beauty	30.02	5	......	......
Landreth	30.45	10	......	......	Livingston's Globe	30.58	5	......	......
Early Michigan	30.67	20	30.70	11	Livingston's Acme	30.46	14	......	......
Marvel	30.03	10	......	......	Greenhouse varieties:				
Bloomsdale	29.99	16	......	......	Sunrise	30.58	15	30.29	7
Red Rock	30.55	6	30.58	11	Sterling Castle	30.54	12	30.11	5
Trucker's Favorite	30.06	8	......	......					
New Glory	29.78	9	......	......	Average	30.46	......	30.39	......

As shown in Table 3 the average freezing point of the 19 varieties was 30.46° F., and the greatest difference in the freezing points of any two varieties was 0.89° F. No consistent difference in results is noticeable between early and late varieties. It is also shown that full-grown green tomatoes in general did not show any significant difference from ripe fruit in their freezing points. The greatest difference was 0.29°, which is of little practical importance.

UNDERCOOLING.

Tomatoes, along with many other fruits and vegetables, may be undercooled to a considerable extent.[3] Briefly, undercooling is the cooling of the tissue, without actual freezing, below the true freezing point. The freezing point is the temperature at which ice crystals begin to form in the tissue, with subsequent injury to the surrounding tissue. Experiments have shown that tomatoes will often remain in this undercooled state for several hours without injury provided they are undisturbed.[4] Six whole Sunrise tomatoes were placed in a temperature of 22° F. In seven hours after passing 32° F. the specimens reached an average maximum undercooled temperature of 22.63° F. Shortly after this, without being disturbed in any way, freezing commenced, and the temperature rose to the actual freezing point of 30.64°, where it remained for several hours. Experience has shown that at any time after the temperature of a tomato goes below its true freezing point, or, in other words, at any time it is undercooled it can be made to freeze by a sudden jar. This fact is of practical importance to growers, and especially to shippers, because if a shipment is known to have been subjected for any length of time to a temperature below the freezing point of tomatoes part or all of the fruit may be undercooled but not frozen provided they have not been disturbed. If the temperature is raised above the freezing point within a limited time, it is possible that the tomatoes will not be frozen. Tomatoes, however, that are subject to a freezing temperature while actually in transit will probably freeze with little or no undercooling, owing to the constant jarring received from the vibration of the car or truck. It is reasonable to assume that in general tomatoes in storage or at rest will undergo a lower temperature without injury than they would in transit.

Other observations were made on the freezing points of whole fruits in an air bath in which the temperature and rate of fall of the temperature could be accurately controlled. Dry tomatoes were placed in the compartment and the temperature lowered gradually in three hours from 50° to 32° F. This allowed the fruits to come to the same temperature irrespective of their size. Water was then sprinkled over them. When the temperature reached 30.9° the water on the surface froze, but the tomatoes did not show frozen spots until an air temperature of 30.3° F. was reached. Usually much greater undercooling occurred with tomatoes with an unbroken skin. The temperature then was maintained at 29° F. Freezing

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[3] See Department of Agriculture Bulletins 895 and 916 for a discussion of undercooling in potatoes (5 and 6).

[4] Actual injury is not necessarily caused by the low temperature, but it directly follows the formation of ice crystals within the cells or intercellular spaces.

always occurred first in the tissue directly beneath each drop of water, and there was no doubt that inoculation of this tissue from contact with ice at these points caused the tissue to freeze. Earliana and Sunnybrook tomatoes showed frozen spots more quickly than the Beauty variety, and the latter froze much quicker than the Trucker's Favorite, Ponderosa, Greater Baltimore, and Stone varieties. Green tomatoes always undercooled less than ripe tomatoes of the same variety, but the difference between the undercooling points of ripe and green tomatoes in the Earliana type is less than in other varieties.

Some tomato varieties have a marked tendency to crack at the stem end. This is especially true of Chalk's Early Jewel, Earliana, New Century, and Sunnybrook Earliana. Such tomatoes undergo scarcely any undercooling and are therefore easily injured. But even when the skin is not visibly broken the Earliana variety does not undercool so much as some other varieties, as, for example, the New Century, which resembles Trucker's Favorite and Livingston's Globe in that it has a tough cuticle (*3*). Hundreds of tomatoes of several varieties were tested, but none were found with freezing points below 29.78° F. A tough skin and no tendency to crack at the stem end are evidently good characters to breed for in order to obtain varieties resistant to freezing.

In those varieties in which the blossom end turns red much before the stem end freezing occurs first at the stem end. The freezing points of the two ends of the tomato were determined by thermocouples. In partly ripened tomatoes tissue from the ripe blossom end showed a freezing-point depression a few tenths of a degree lower than tissue from the green stem end; however, in no case did it amount to as much as 0.4° F. This difference may be due to the formation of sugars in the ripening cells.

EFFECT OF COLD ON THE TOMATO PLANT.

The tomato plant belongs to a class of annuals which show but little adaptation to low temperature and can not be frozen without killing. On exposure to low temperature the plants become somewhat more difficult to freeze—that is, the freezing point is lowered—but as soon as ice formation occurs within the tissues the cells are killed.

During the usual weather conditions which precede the first killing frost in autumn the night temperature is usually somewhat above 32° F. but low enough to increase the accumulation of osmotically active sugars, with a consequent lowering of the freezing point of the plant sap. Attendant also upon the low temperature there may be a stopping of growth, with the formation of a thicker cuticle over the surface of young leaves and fruits. A thickened cuticle is of impor-

tance in frost resistance, for it allows the tissue beneath it to be undercooled below the freezing point.

As shown in a previous publication (*2*), the freezing-point depression of tomato-plant juice can be increased about 0.2° F. by exposing the plants for five days at 37.4° F. This may be considered an adaptation to low temperature; but it can not be carried far, because certain physiological disturbances occur which will result in the death of the plants although they are not frozen. It is therefore seen to be impossible to harden tomatoes to make them immune to frost, like cabbages and such other biennials and perennials, which can be frozen stiff without injury if they are allowed to adapt themselves to cold during a preliminary hardening period. We have to deal with the factors of undercooling and freezing-point depression in the case of tomatoes rather than with frost immunity.

STUDIES IN THE FIELD.

In experiments on the freezing of tomatoes in the field, a series of temperature measurements was made by means of mercury thermometers of temperature at Bell, Md., on a clear, still night on which the first frost of the autumn of 1919 occurred. The temperature measurements from which the data shown in Figure 1 were obtained were taken in a field in which 26 varieties of tomatoes were under test to determine their relative frost resistance. The field was located on a gentle slope, and down the incline an almost imperceptible stream of cold air flowed.[5] The current of cold air was rather shallow, flowing down hill in a layer only a few feet deep. The coldest part of the current was about 10 inches above the ground. At the ground the lower part of this current seems to have been warmed by radiation from the earth. At 18 inches above the ground the air current was somewhat warmer, owing to the tendency of the denser and colder air to move downward. One can frequently see smoke or mist floating on these denser strata near the ground.

The curves in Figure 1 give the air temperatures at ground level and 6 inches and 18 inches above the surface of the ground as well as the surface and internal temperatures of three tomatoes situated from 10 to 12 inches above ground. These temperatures were determined by thermometers placed at the surface of each tomato or inserted into holes in the fruit made by removing plugs of the same size as the thermometers with a cork borer. From the graphs it is seen that the temperature within the tomato lagged considerably behind that of the air immediately outside. This lag is due to the heat capacity of the tomato and increases with the size of the fruit. With the out-

[5] For a more detailed discussion of temperature relations, see "Frost and the Prevention of Damage by It." (7).

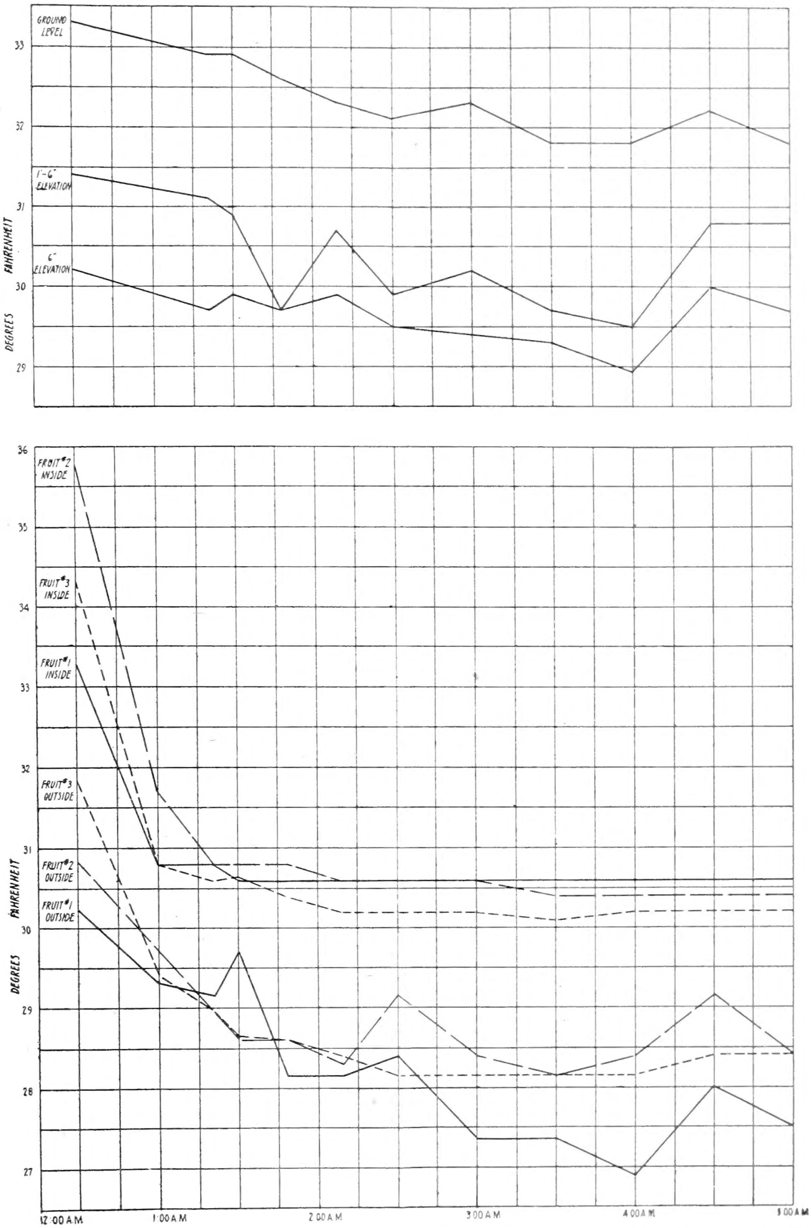

FIG. 1.—Hourly temperature measurements taken at Bell, Md., on the night of the first frost of the autumn of 1919. Thermometers were placed at ground level and at elevations of 6 and 18 inches; also at the surface and centers of three tomatoes on the vine at about 12 inches elevation.

side temperature at 30.2° and falling to 29.5° F., it required about 1½ hours for the temperature of tomato No. 1 to fall from 33.3° to 30.6° F. It is, therefore, possible, on account of this temperature

lag, to have a short duration of temperatures somewhat below freezing without injuring the fruits. During the night considerable dew was deposited in droplets on the upper surface of the tomatoes. The dew began to freeze when the temperature inside of the tomatoes reached 31.1° F. This is scarcely less undercooling than the water on adjacent leaves showed, but dew on the leaves froze a little quicker than that on the fruits because of the radiation of heat from the latter. When the tomatoes had reached 30.6° F., they began to freeze at the surface where the thermometers had been introduced, and dark-colored areas became visible, due to changes in the reflection of light from the frozen tissue. The final freezing points of fruits Nos. 1, 2, and 3 were 30.6°, 30.4°, and 30.2° F., respectively. Owing to the heat liberated by the freezing out of water, the inside temperature of the tomatoes did not fall below 30° at any time, although the outside temperature fell to 26.9° F. In tomatoes which were undisturbed it was observed that freezing did not begin as soon in sound tomatoes as in those in which the skin was broken. It will be noted that no undercooling was recorded. This was probably due to the freezing dew on the surface of the tomatoes. Previous investigations by the Bureau of Plant Industry of freezing injuries to potatoes showed that wet potatoes freeze more readily than dry ones (*6*). Freezing began on young fruits first and on the top side. on which dew had deposited.

No differences could be detected in the freezing points of the plants in 26 varieties in this field. If differences exist it would require carefully equalized temperatures to detect them. The young leaves freeze first, and in these the injury occurs first along the vines. The average freezing point of tomato leaves was found to be 30.22° while stems froze at 29.99° F.

Tomatoes which lie directly upon the ground are warmed by conduction from the warm earth and do not freeze as quickly as those situated up on the vine. When the vines are very leafy those tomatoes which hang on the inner branches are not frozen as soon as exposed fruits, because they are protected from radiating their heat by the surrounding leaves.

SUMMARY.

(1) A large portion of the tomato crop grown in the Southern States and shipped north in the late winter is in constant danger of frost injury while in transit.

(2) The average freezing point of 19 commercial varieties was determined to be 30.46° F.

(3) A difference of 0.89° F. was found between the freezing points of certain varieties of tomatoes.

(4) No consistent difference was found between the freezing points of ripe and practically full-growr. green tomatoes of the same varieties.

(5) No consistent difference in freezing points of early and late varieties was found.

(6) Six average tomatoes were undercooled in the laboratory to 22.63° F. before freezing commenced. The freezing point was 30.64 F.

(7) Tomatoes can be undercooled below their freezing point and if undisturbed may remain without freezing for a limited time; however, at any moment while undercooled a slight jar is liable to cause freezing.

(8) The possession of a thick skin with little tendencey to crack is apparently an important factor in the frost resistance of tomatoes. Under field conditions such a covering favors the undercooling of the fruits by preventing inoculation of the tissue from ice formed on the surface.

(9) The freezing point of ripe parts of a tomato may be slightly lower than for green parts of the same fruit. Tomatoes on the vine freeze on the upper stem end first partly for the above reason and partly because dew deposits on the upper side and tends to inoculate the surrounding tissues.

LITERATURE CITED.

(1) Beattie, James H.
1921. Tomatoes for canning and manufacturing. U. S. Dept. Agr., Farmers' Bul. 1233, 20 p., 7 fig.

(2) Harvey, R. B.
1918. Hardening process in plants and developments from frost injury. *In* Jour. Agr. Research, v. 15, no. 2, p. 83–112, 3 fig., pl. 7–11, A (col.) Literature cited, p. 108–111.

(3) 1919. Importance of epidermal coverings. *In* Bot. Gaz., v. 67, no. 5, p. 441–444, 2 fig.

(4) Taylor, George F.
1920. Some improvements on the needle type thermocouple for low temperature work. *In* Jour. Ind. and Eng. Chem., v. 12, no. 8, p. 797–798, fig. 1.

(5) Wright, R. C., and Harvey, R. B.
1921. The freezing point of potatoes as determined by the thermoelectric method. U. S. Dept. Agr. Bul. 895, 7 p., 1 fig.

(6) Wright, R. C., and Taylor, George F.
1921. Freezing injury to potatoes when undercooled. U. S. Dept. Agr. Bul. 916, 15 p., 1 fig., 1 pl. Literature cited, p. 15.

(7) [Young, Floyd Dillon].
1920. Frost and the prevention of damage by it. U. S. Dept. Agr., Farmers' Bul. 1096, 48 p., 24 fig.

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